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FINAL REPORT

FURTHER DEVELOPMENT AND TESTING OF FALL RYE AND SPRING RYE MATERIAL HAVING REDUCED VISCOSITY

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Further development and testing of fall rye and spring rye material having reduced viscosity.

Final report on ADF project # 96000196

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Abstract/Summary

The objective of this project was to develop rye lines with reduced grain viscosity and to test their feed value for both poultry and swine. A secondary objective was to try and understand the biochemical basis for the reduced viscosity. Through selection over a number of generations populations of spring and fall rye with significantly reduced viscosity and also a population of spring rye with very high viscosity were developed. Rye with reduced viscosity had better feed value. Reduction in the molecular weight of the arabinoxylan cell wall components appeared to be the cause of reduced viscosity.

Executive Summary

Background - In western Canada, rye is primarily used as a feed grain for cattle, swine and chickens. Rye is the most winter hardy grain crop and hence is the only fall-seeded grain crop that can be reliably grown. Approximately 90% of the rye produced is fall rye. Because of the benefits that such a fall-seeded crop brings (better use of limited precipitation, better soil cover, reduced tillage, good weed competition, protection of duck nesting habit), rye should have a significant part to play in a sustainable western Canadian agriculture. However the usage of rye as a feed grain is limited by feeding problems, particularly with monogastrics such as swine and chickens. Rye grain has much higher viscosity than other cereals and this may be the cause of the feeding problems. At the start of this project it was known that the addition to rye feed of enzymes that breakdown the components of rye thought to be responsible for the high viscosity resulted in improved feed value. Genetic variability for viscosity levels had been demonstrated, and in an earlier project funded by ADF, the development of low viscosity populations had begun. The objectives of this study were to: a) continue to develop through selection populations of spring and fall rye with reduced viscosity; b) at the same time develop a population of spring rye with very high viscosity for scientific studies on the causes of viscosity; c) using the material produced in a) produce sufficient quantities of grain for feeding trials with chicks and swine and d) investigate the causes of high viscosity in rye at the biochemical level.

After seven years of divergent selection for viscosity, populations of spring rye with either very low or very high viscosity have been developed. This was made possible by growing two generations of the material per year for each of the seven years. Because of the need to vernalize fall rye each generation, the advance in the reduction of viscosity has not been as rapid. Because of this, spring material was utilized in feeding studies and biochemistry studies. As population development proceeded it became necessary to modify the technique used for viscosity screening because of the significant changes in viscosity that had taken place. The viscosity of the most recent selections of spring rye is similar to that of wheat. At the other end of the spectrum, a rye population with extremely high viscosity has been developed. While of no value to the feed industry, this material is of scientific value and given the interest in the role of soluble fibre in the human diet, may be of value in the future in the functional food/nutraceuticals industry.

Biochemical studies confirmed that high molecular weight arabinoxylans, a cell wall component, are responsible for the high viscosity of rye. This would suggest that gene(s) for enzymes involved in the lengthening of the arabinoxylan molecules differ in the two populations after selection. With recent advances in genomics it may be possible to determine the enzymes involved using the material generated in this project and use a more directed approach to achieve significant changes in viscosity. Although the arabinoxylans are cell wall components, we have no evidence from our work over the last eight years that manipulation of the levels in the seed has been detrimental to plant growth and performance. Arabinoxylans have been earlier implicated in cold hardiness but again our work with low viscosity rye has failed to provide any evidence of this. Winter survival in the field of low viscosity material has been the same as that of regular rye.

Feeding studies with both chicks and swine tend to confirm that a genetic reduction in viscosity results in better feed value paralleling results with enzymes. However results were not as conclusive as hoped.

As pointed out elsewhere, these feeding trials were performed with rye with reduced viscosity but not to the levels that have since been achieved through further selection. Since those experiments were performed significant advances have been made to further reduce viscosity. Material is now available with viscosity similar to wheat. This seed is now available for increased to provide the quantities sufficient for further feeding trials.

Technical Report

Fall Rye - Population improvement

This work commenced as part of a previous ADF project. In 1991, 187 single plants of fall rye (Musketeer) had been harvested and the seed analyzed for viscosity. Approximately twenty seeds of the ten plants with the lowest viscosity were germinated, artificially vernalized and transplanted to the field in the spring, away from any other fall rye and allowed to cross-pollinate. All plants were harvested, and again after harvest viscosity of the plants was analyzed. This process was carried out between 1992 and 1996. Over these five years the mean viscosity of the population decreased significantly.

Year	# plants analyzed	Mean viscosity (cps)	Range
1991/2	187	53	7 - 192
1992/3	75	34	13 -175
1993/4	146	22	7 - 66
1994/5	172	26	6 - 125
1995/6	200	15	5 - 57
1996/7	60	56 (3:1)	8 - 181

Two hundred plants grown from seed of plants identified as having low viscosity after the 1996 harvest were vernalized and transplanted into the field in the spring of 1997. Establishment and vigor of the plants was disappointing despite reasonable growing conditions. It is likely that the population was suffering from inbreeding depression and so further selection within it was probably not worthwhile. Crosses were made at random between these plants as in previous generations but this material was not utilized further. Instead, the material was harvested as single plants and despite the low vigor, the viscosity of the grain of the fall rye plants was assessed over the winter. In order to

expand the gene pool it was decided to make crosses between progeny of some of these plants and plants of the Russian fall rye cultivar Saratovskaja 5 (Sara 5) that had been shown to have relatively low viscosity (see later). One hundred low viscosity fall rye seedlings (ten seedlings from each of the ten plants with lowest viscosity in 1997) were vernalized in the Phytotron and transplanted into the field in May 1998. An additional 100 seedlings of the low viscosity line Sara 5 were also vernalized and transplanted into the field. Crosses were made among the two groups of plants in 1998. Viscosity of the 60 strongest surviving plants and of the 100 Sara 5 plants was assessed over the winter of 1998/99 and the results are shown below.

	Low Viscosity Fall Rye '98 (3:1 dilution)				
Sample No.	**Cps.**	**Cps.**	**Cps.**		**Mean Viscosity**
75-7-5	11.9	11.9	12.1		12.0
75-7-6	16.2	13.6	13.2		14.3
60-17-1	14.8	15.1	13.9		14.6
153-8-4	16.9	17.9	17.2		17.3
159-16-5	20.1	17.5	15.9		17.8
153-8-1	18.7	19.1	18.5		18.8
60-17-10	19.7	19.5	17.9		19.0
75-7-10	19.7	21.9	19.7		20.4
153-8-6	23.9	21.9	18.5		21.4
60-18-2	23.9	23.4	23.5		23.6
75-6-6	23.5	22.9	24.5		23.6
153-8-5	22.9	25.4	23.1		23.8
75-7-8	25.1	25.4	25		25.2
153-8-8	26.9	28.7	23.9		26.5
153-14-7	22.7	34.6	25.4		27.6
60-17-5	25.4	31.9	28.3		28.5
60-16-9	24.2	34.1	34		30.8
75-7-3	31.9	32.4	31.1		31.8
75-13-2	36.1	24	37		32.4
159-1-8	33.9	34.1	30.6		32.9
60-17-2	35.4	33.1	31.6		33.4
60-16-7	34.9	33.6	34.1		34.2
75-7-7	25.4	42.1	38.7		35.4
75-7-9	36.9	37.1	34.7		36.2
153-8-9	38.9	37.7	33.2		36.6
153-14-1	36.1	36.2	38.1		36.8

153-14-4	33.9	39.8	38.7		37.5
75-7-4	38.7	36.9	38.1		37.9
75-7-1	39.7	41.9	33.7		38.4
60-17-9	35.9	43.9	41.4		40.4
60-18-3	43.3	40.2	40.1		41.2
60-18-8	44.1	40.7	41.6		42.1
153-14-1	45.6	42.8	40.4		42.9
153-14-3	46.3	50.6	39.8		45.6
75-13-10	45.2	45.4	47.1		45.9
153-14-9	46.3	47.1	46.3		46.6
60-17-3	65.1	49.8	46.8		53.9
60-18-10	64.6	47.8	49.4		53.9
153-14-2	60.2	60.1	50.2		56.8
60-17-7	69.1	69.1	50.4		62.9
153-14-6	64.8	67.5	65.5		65.9
60-17-4	65.8	72.3	74.4		70.8
60-16-4	71.1	75.2	66.5		70.9
75-13-7	87.8	79.2	81.4		82.8
153-14-10	87.8	79.7	84.5		84.0
75-13-8	96.2	90.5	92.2		93.0
75-13-3	127	74.1	81.8		94.3
159-16-8	97.2	98.5	89.2		95.0
60-17-6	118	90.2	96.5		101.6
60-18-1	102	131	144		126
75-13-5	156	102	123		127
153-14-8	142	125	134		134
60-18-5	148	152	147		149
60-18-6	145	161	164		157
60-18-7	502	489	519		503
			Mean Viscosity =		59.5

	Saratov '98 Viscosities (3:1 dilution)				
Sample No.	**Cps.**	**Cps.**	**Cps.**		**Mean Viscosity**
91	25.4	22.9	24.3		24.2
15	24.6	26.9	27.2		26
10	31.4	25.2	25		27.2
41	34.1	32.9	32.1		33.0
22	31.9	34.1	33.6		33.2
65	39.8	32.1	33.6		35.2
98	33.4	37.4	37.9		36.2
80	38.7	42.4	37.6		39.6
61	43.8	41.2	36.9		40.6

77	42.4	41.1	42.1		41.9
1	43.1	42.4	43.1		42.9
60	45.1	46.1	37.9		43.0
97	46.8	45.3	43.9		45.3
66	43.1	47.4	50.4		47.0
16	44.6	50.4	60.1		51.7
85	67.8	63.9	67.1		66.3
4	71.1	70.5	71.5		71
30	69.7	74.5	69.7		71.3
67	72.8	76.8	73.5		74.4
93	102	65.8	64.1		77.3
88	90.5	72.8	75.5		79.6
45	73.5	83.5	82.2		79.7
2	88.2	72.1	89.6		83.3
47	85.5	82.7	86.9		85.0
17	88.5	82.6	89.6		86.9
95	96.5	85.8	82.5		88.3
63	91.8	89.5	86.6		89.3
99	89.2	91.3	96.4		92.3
25	101	96.2	90.9		96.0
52	102	95.2	91.8		96.3
35	102	98.9	91.2		97.4
86	100	94.2	99.5		97.9
68	98.9	98.9	102		99.9
81	96.9	101	102		100
26	121	89.1	101		104
34	134	92.5	89.8		105
36	128	101	102		110
71	137	102	101		113
57	153	102	92.2		116
28	127	132	102		120
51	119	126	124		123
20	124	131	126		127
82	147	102	141		130
69	137	131	140		136
21	145	138	131		138
32	144	138	142		141
87	131	174	132		146
39	156	161	150		156
5	163	144	164		157
43	156	145	171		157
14	169	164	190		174
44	184	173	170		176
31	167	201	171		180

50	184	187	172		181
40	164	189	195		183
76	169	195	190		185
29	199	201	189		196
78	237	194	164		198
7	170	236	194		200
42	242	185	190		206
100	214	229	202		215
72	249	217	213		226
48	237	234	224		232
9	239	243	216		233
19	250	209	261		240
46	263	257	204		241
96	254	240	257		250
75	261	289	219		256
55	287	259	247		264
23	269	286	241		265
92	236	302	259		266
12	276	250	271		266
94	269	302	249		273
79	271	277	296		281
58	316	269	294		293
90	254	286	341		294
89	347	259	312		306
70	321	314	346		327
73	361	312	352		342
8	346	362	322		343
3	352	369	349		357
84	346	331	426		368
62	369	384	392		382
13	413	359	378		383
49	407	389	362		386
27	416	484	423		441
38	469	427	441		446
6	489	548	550		529
54	571	646	581		599
24	628	621	596		615
11	689	648	613		650
			Mean Viscosity =		183.8

Based on these results, hybrid seed of four crosses which had been made in 1998 between parents having good vigor and relatively low viscosity levels (20 seeds of each line of the crosses 60-18-10 X 60-17-2; Sara #61 X 60-17-2; Sara #60 X 75-6-6; Sara #1 X 60-16-9) were vernalized and grown in the greenhouse over the summer of 1999. These were allowed to cross-pollinate in the greenhouse and 240 seeds were planted at the Department's North Seed Farm in the fall of 1999 as spaced plants. There was a substantial amount of winter-kill along the west side of the plot where at least 2 entire rows did not re-emerge in the spring. Some material was also lost to gophers. The 81 surviving plants were allowed to cross-pollinate with each other and were harvested as individual plants at maturity. Seed yield was much improved compared to previous years. This material was subjected to viscosity analysis in the fall of 2000 and will serve as a source of high viscosity fall rye germplasm for future studies and/or breeding by ourselves or others. The grain viscosity levels of the 80 plants are shown below.

Fall Rye Viscosities 2000 (3:1 dilution)

Sample No.		Cps.	Cps.		Mean Viscosity
19		10.8	11.1		11.0
60		13.1	11.6		12.4
44		13.4	13.1		13.3
39		14.4	14.1		14.3
12		14.7	15.9		15.3
58		14.6	16.6		15.6
9		16.1	17		16.6
41		17.9	15.3		16.6
73		17.5	16.7		17.1
25		19.1	19.2		19.2
40		19.2	19.4		19.3
17		21.2	20.4		20.8
78		21.7	19.9		20.8
30		21.5	20.2		20.9
31		21.4	20.7		21.1
16		22.9	20.2		21.6
2		21.3	22.7		22.0
59		22.5	21.7		22.1
32		22.9	21.7		22.3
42		23.9	21.7		22.8

54		24.6	22.7		23.7
43		24.7	23.2		24.0
27		23.2	24.9		24.1
10		24.9	24.2		24.6
48		24.7	25.4		25.1
7		28.9	25		27.0
26		32.4	24.5		28.5
15		32.1	25.4		28.8
70		36.6	23.5		30.1
63		35.2	25.4		30.3
57		36.2	24.7		30.5
33		41.6	22.7		32.2
75		36.2	34.2		35.2
79		32.6	38.7		35.7
47		36.7	35.2		36.0
45		36.6	37.3		37.0
22		38.2	37.2		37.7
52		41.6	36.7		39.2
46		37.4	41.6		39.5
67		38.4	40.7		39.6
64		41.6	38.2		39.9
69		42.6	39.7		41.2
72		44.4	41.2		42.8
55		50.3	36.1		43.2
77		44.8	41.6		43.2
28		44.6	42.1		43.4
66		43.6	44.1		43.9
65		44.1	44.3		44.2
62		46.9	42.1		44.5
71		48.4	46.1		47.3
56		49.4	47.3		48.4
74		49.8	47.6		48.7
38		50.3	48.1		49.2
36		49.6	49.4		49.5
68		50.8	49.4		50.1
80		58.2	45.8		52.0
21		58.9	54.3		56.6
50		65.1	50.6		57.9
24		68.8	50.6		59.7
14		67	60.5		63.8
4		62.5	68.9		65.7
34		68.8	63.1		66.0
20		63.3	68.7		66.0
61		64.8	67.8		66.3

3		66.1	67.5		66.8
11		69.8	67.1		68.5
5		71.7	68.1		69.9
13		74.3	77.6		76.0
1		75.5	77.2		76.4
8		85.2	69.7		77.5
51		86.8	82.5		84.7
29		91.2	85.5		88.4
53		92.9	90.9		91.9
23		93.5	99.9		96.7
76		94.9	101		98.0
6		102	111		107
18		121	125		123
49		131	117		124
35		141	134		137.5
37		136	140		138
			Mean Viscosity =		**46.9**

Note that the mean viscosity is now lower than that of the source 1998 populations. Now that vigour has been restored a new population could be reconstituted from some of the lower viscosity plants.

Fall rye – Development of low viscosity populations from crosses

In each of the earlier years of the project, random crosses were made between plants derived from different individuals the previous year (at the time viscosity of the grain to be produced on the plants was of course unknown). After the viscosity of the grain from the single plants had been determined, crosses that had been made between two plants producing grain with low viscosity were identified and the seed of these crosses was germinated, vernalized and planted in the greenhouse in isolation and ultimately multiplied in isolation. Small increase plots of two populations produced from crosses made in 1992 were grown in 1993/94 and larger plots grown in 1994/95 along with Musketeer as a control, one of these (with the lowest viscosity – referred to as 92 short) was grown again in 1995/96. Similarly, three isolations from crosses made in 1993 were grown as small plots in 1994/95 and two of these were grown again in 1995/96.

A Russian line that had been identified by Dr. Grant McLeod as having low viscosity (Saratovskaja 5 = Sara 5) as having low viscosity was also grown in 1995/96. The results are summarized below:

Year grown	Cross #	Mean viscosity (cps)
1994/95	92 short (large seed)	14
	92 short (small seed)	20
	92 tall (large seed)	23
	92 tall (small seed)	27
	Musketeer (large)	19
	Musketeer (small)	40
	93 #1	11
	93 #2	10
	93 #3	7
1995/96	92 short	12
	93 #2	16
	93 #3	9
	Sara 5	10
	Musketeer	23

In 1996 grain was harvested from some of these increase plots of fall rye that had been developed as part of the previous ADF project. Nothing was done with this seed over the fall/winter of 1996/7 because of the termination of the previous project. Seed (approx. 6kg.) of 93-2 and Sara 5 was planted by Dr. Grant McLeod (AAFC Swift Current) in Southwest Saskatchewan on land belonging to Mr. Rod Johnson in mid-September of 1997. This was done with a view to providing large quantities of grain of the two low viscosity fall rye populations for chick and animal feeding trials. However the increase was not successful due to poor establishment and low moisture. Excessive weed growth impeded harvest. The harvested grain needed to be thoroughly cleaned before viscosity could be assessed. Given the excellent increase of spring material (see later) this material was not developed further.

Fall Rye – Material from Europe

Some fall rye material was received from Finland and two replicates of nine small plots (including local controls) were planted on September 10th 1997 on University land. The purpose of this work was to investigate viscosity levels in this material (in view of the discovery that Sara 5 had low viscosity – see above) and also to make low viscosity single plant selections that could be used to broaden the genetic base of low viscosity material. All material survived the winter and ten to twelve plants of each line were enclosed under isolation bags to try an prevent/minimize cross-pollination. Grain was harvested and viscosity was determined on three duplicate samples of grain from both cross-pollinated material as well as from plants that had been isolated. No Finnish material had viscosity lower than material already in the program and most was much higher. Isolation to prevent outcrossing did not appear to have any significant affect on viscosity, as the viscosity values of lines produced under isolation were similar to those produced under cross-pollination (se below).

	Viscosity of 97-'98 Investigation Rye Plots Cross-Pollinated (data for each replicate)				
Variety/line	**Cps.**	**Cps.**	**Cps.**		**Mean Cps.**
1 Musketeer	41.4	45.6	43.4		43.5
2 93 LVFRx2	22.9	24.6	21.9		23.1
3 Sara Lo Blk	19.7	16.9	17.5		18.0
4 Konni	77.2	81.8	86.9		82.0
5 Sara unselected	21.9	19	19.2		20.0
6 Jaroslav	38.6	41.2	32.1		37.3
7 Zulpan	35.6	33.6	41.9		37.0
8 92 LVFR short	31.6	23.2	21.1		25.3
9 Hjan Juss	93.9	86.8	95.2		92.0
10 Sara unselected	21	23.4	23.1		22.5
11 Hjan Juss	123	141	138		134
12 Konni	81.5	63.1	69.7		71.4
13 Sara Lo Blk	18	20.5	18.9		19.1
14 92 LVFR short	35.2	36.1	36.2		35.8
15 93 LVFRx2	25.4	25.4	23.9		24.9
16 Musketeer	49.9	43.9	56.8		50.2

17 Zulpan	68.9	74.7	65.5		69.7
18 Jaroslav	89.2	87.5	70.8		82.5
			Mean		**49.4**

Spring rye - Population improvement

It was reported in the final report of the previously funded ADF project that selection for both low and high viscosity had begun in the spring rye cultivar Gazelle. This was done because of the slow rate of advance that is possible in fall rye due to its long growing season and need for vernalization. It was also hoped that divergent selection would provide rye populations with widely differing viscosity levels so that the relevance of viscosity to feed value could be determined. This process began in 1993 when single plants of the cultivar Gazelle, a spring rye, were screened for viscosity. Two hundred and forty-four single plants were harvested. Single seeds from each of the 25 plants with highest viscosity and 25 plants with lowest viscosity were grown in separate isolation areas in a greenhouse and the plants allowed to cross-pollinate with each other. Twelve seeds from each plant were taken and bulked to form a low viscosity and a high viscosity bulk. These bulks were seeded in 1994 as spaced plants in isolation from each other and other rye. Single plants were harvested, viscosity analysed and a similar process repeated in 1995 except that ten seeds were selected form each of the ten lowest (and highest) viscosity plants for cross-pollination in the greenhouse. The results of these earlier years of selection are presented below.

Year	Selection	No. of plants	Mean viscosity (cps)	Range
1993	-	244	54	8 - 227
1994	Low	125	21	5 - 82
1994	High	185	49	11 - 230
1995	Low	93	11	4 - 41
1995	High	112	49	10 - 299

In 1996, before the termination of the previous project, 16 progeny from each of the 10 lowest viscosity plants in the low viscosity population were grown in the greenhouse in isolation and allowed to cross pollinate. Sixteen progeny from the 10 highest viscosity plants in the high viscosity population were treated similarly. Seed from these two

populations was harvested in bulk and 240 seeds from each bulk were planted into the field in 1996 as spaced plants. Viscosity of these plants was determined during the winter of 1996/97. The divergent selection process was continued in 1997 through until 2000. The detailed results of these analyses have been presented in progress reports and are not presented here. Instead the data for the seven rounds of selection are presented below. The number of plants screened for viscosity each year varied slightly depending on germination, plant survival and amount of seed produced. Note that because of changes in viscosity, the level of dilution of wholemeal to buffer that was used in the viscosity analysis had to be adjusted so that a range of viscosity could be detected. For the 1996 harvest viscosity in the low viscosity population had been reduced to point that a 5:1 dilution did not differentiate among the lines significantly. Hence from this point on a 3:1 dilution was used for the low viscosity population. Similarly in 1997, viscosity levels of many samples were so high that accurate viscosities could not be determined, hence a greater dilution (6:1) was used for this population for the next four years.

Year	Low mean	Range	No. of plants harvested	High mean	Range	No. of plants harvested	Dil. used	Plants x seeds
1993	54	8 to 227	244	54	8 to 227	244	5:1/5:1	25x1
1994	21	8 to 82	125	49	11 to 230	185	5:1/5:1	10x10
1995	11	5 to 52	93	49	11 to 290	112	5:1/5:1	10x16
1996	61	12 to 364	117	123	12 to 482	120	3:1/5:1	10x16
1997	15	5 to 86	200	49	9 to288	210	3:1/6:1	10x16
1998	37	8 to 333	92	149	20 to 480	66	3:1/6:1	10x16
1999	17*	6 to 63	109	305	11 to 990	171	3:1/6:1	10x16
2000	20	7 to 104	102	284	33 to 1000	196	3:1/6:1	

* greenhouse grown due to poor field germination

As part of the divergent selection program in spring rye, plots of the low and high viscosity selections were thinly planted in two distant locations on University property in 1997 using remnant seed from the 1996 harvest. About 120lbs of rye were harvested from each bulk plot. After cleaning about 80lbs of each selection remained. The low viscosity material had a viscosity of 10 cps (3:1 dilution) and the high a viscosity of 95 cps (5:1 diluion). Some of this seed was used for laboratory tests (see later) and the remainder was increased again in 1998 as one acre increases. From the two one-acre increase plots 775kg of the low viscosity material was obtained and 459kg of the high.

Presumably because of environmental effects the viscosities of the two populations were not as divergent as in the previous year. The viscosity of the low population was 43 cps (3:1 dilution) and that of the high was 87.3 cps (5:1 dilution). The material produced in each of these two years was used for feeding trials with chicks and swine (in collaboration with Drs Leigh Campbell and Phil Thacker, Department of Animal and Poultry Science, University of Saskatchewan) and in biochemical studies by Dr Sanaa Ragee, at the time a PhD student in the Department of Applied Microcbiology and Food Science, University of Saskatchewan – supervisor Dr. Bob Tyler.

Biochemical studies

The results of Dr Ragee's work were presented in her thesis which she successfully defended this past winter. The results of this work have also been accepted by the Journal of Agricultural and Food Chemistry and will be published shortly as two papers. These are appended to this report and summarized below.

Dr Ragee's studies confirmed that extract viscosity was positively correlated with soluble dietary fibre and water-extractable arabinoxylan content when rye was compared with wheat. Within rye, it was shown that the proportion of a high molecular weight fraction in the water-soluble extract was greater in rye lines with higher viscosity. Treatment by the enzyme xylanase and other enzymes followed by gel filtration chromatography indicated that the high molecular weight fraction consisted primarily of arabinoxylan rather than other compounds. Microscopic examination of kernels of low and high viscosity extract rye indicated that the high viscosity line had larger aleurone cells and thicker endosperm cell walls.

Extract viscosities of rye flours were higher than those of the corresponding whole meals indicating concentration of the water-soluble arabinoxylan into flour during roller milling. In baking, extract viscosity of rye and rye/wheat blends was positively correlated with dough stability, indicating a higher strength for flours from higher extract viscosity ryes. However loaf volume was negatively correlated with loaf volume in rye/wheat blends.

Structural analysis of water-extractable arabinoxylan from low and high viscosity rye by H-NMR indicated that the arabinoxylan from high viscosity rye was a much less branched molecule than that of low viscosity rye with fewer disubstituted Xylp residues. Analysis by HPLC/triple detection revealed that arabinoxylan from high extract viscosity rye had a higher molecular weight.

Chick and swine feeding trials

Inclusion of wholemeal rye, particularly the high extract viscosity material, in chick diets seriously impeded growth performance and feed efficiency (see manuscript). Part of the arabinoxylan survived the bread making process and also exerted an effect in chicks, although considerably lower digesta viscosities were observed in chicks fed bread diets rather than whole meals.

The results of the swine feeding trial have been published in the Journal of Animal and Feed Sciences (paper appended). In summary, positive results were obtained (swine fed lower viscosity rye exhibited higher daily feed intake and higher daily gain). These did not reach significance and were still much lower than a more traditional barley diet.

It should be noted that all feeding experiments were performed with material that had only undergone three rounds of selection prior to multiplication. The most recent low viscosity rye population has much lower viscosity and so might perform much better in feeding trials.

Interest in high viscosity rye

At the outset of this research it was understood that for human consumption the high viscosity of rye was probably beneficial as it is a component of soluble dietary fibre in the human diet. Soluble dietary fibre has been recognized to have beneficial effects. Some high viscosity material was supplied to the POS plant with a view to studyng its value as a source of pure arabinoxylan. Preliminary extractions using a "normal" rye resulted in a very impure product.

As a result no work has yet been carried out with the high viscosity material. If these problems can be resolved then the high viscosity material produced and available in large quantities through this project would be an excellent starting point for further studies and possibly commercialization.

- **Project Developed Materials**

  Appended

Project Photos

N/A

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